Research Article

The Role of Language in Nonlinguistic Stimuli: Comparing Inhibition in Children With Language Impairment

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Purpose: There is conflicting evidence regarding if and how a deficit in executive function may be associated with developmental language impairment (LI). Nonlinguistic stimuli are now frequently used when testing executive function to avoid a language confound. However, it is possible that increased stimulus processing demands for nonlinguistic stimuli may also compound the complexity of the relationship between executive function and LI. The current study examined whether variability across nonlinguistic auditory stimuli might differentially affect inhibition and whether performance differs between children with and without language difficulties.

Method: Sixty children, aged 8–14 years, took part in the study: 20 typically developing children, 20 children with autism spectrum disorder, and 20 children with specific LI. For the purposes of assessing the role of language, children were further categorized based on language ability: 33 children with normal-language (NL) ability and 27 children with LI. Children completed a go/no-go task with 2 conditions comparing nonlinguistic auditory stimuli:

2 abstract sounds and 2 familiar sounds (duck quack and dog bark).

Results: There was no significant difference for diagnostic category. However, there was a significant interaction between language ability and condition. There was no significant difference in the NL group performance in the abstract and familiar sound conditions. In contrast, the group with LI made significantly more errors in the abstract condition compared with the familiar condition. There was no significant difference in inhibition between the NL group and the group with LI in the familiar condition; however, the group with LI made significantly more errors than the NL group in the abstract condition.

Conclusions: Caution is needed in stimuli selection when examining executive function skills because, although stimuli may be selected on the basis of being “nonlinguistic and auditory,” the type of stimuli chosen can differentially affect performance. The findings have implications for the interpretation of deficits in executive function as well as the selection of stimuli in future studies.

Individuals with specific language impairment (SLI) have deficits in receptive and/or expressive language ability with otherwise apparent typical development. However, there is considerable evidence to suggest that language impairments (LIs) are not only limited to language-specific difficulties but also associated with certain cognitive deficits including executive functions such as inhibition, attention, and working memory (for reviews, see Gillam, Montgomery, & Gillam, 2009; Windsor & Kohnert, 2009).

LI is not, however, limited to children with SLI, and a subset of children with autism spectrum disorders (ASDs) has also been shown to demonstrate similar structural language difficulties (Botting & Conti-Ramsden, 2003; Kjelgaard & Tager-Flusberg, 2001; Roberts, Rice, & Tager-Flusberg, 2004). Notably, executive function deficits are also reported in ASD (e.g., Hill, 2004; Joseph, McGrath, & Tager-Flusberg, 2005). However, studies examining deficits in executive functions in both SLI and ASD have produced mixed results (e.g., Ebert & Kohnert, 2011; Noterdaeme, Amorosa, Mildenerger, Sitter, & Minow, 2001). Conclusions vary widely regarding whether executive function deficits are present in children with SLI and children with autism and, if so, which aspects of executive function are affected. Part of the challenge in making these determinations may lie in the wide range of stimuli used to assess executive function abilities.

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Executive Function, Stimulus Effects, and LI

To date, there has been a predominant focus on whether deficits in executive function are specific to stimulus modality. For example, it has been suggested that children with SLI demonstrate deficits in attention in the auditory modality, but not in the visual modality (Dodwell & Bavin, 2008; Noterdaeme et al., 2001; Spaulding, Plante, & Vance, 2008; Townsend & Tallal, 1989). On the surface, this might suggest that the deficits are specific, or enhanced, for auditory information. However, deficits in processing auditory stimuli when testing attention are not always observed (McArthur & Bishop, 2004; Redey-Nagy, 2009), and other studies have suggested difficulties in the visual modality (Finneran, Francis, & Leonard, 2009; Lum, Conti-Ramsden, & Lindell, 2007). A meta-analysis of studies looking at performance on attention tasks in children with SLI reported a significant effect only for the difference between auditory–linguistic tasks and visual tasks (Ebert & Kohnert, 2011). These findings may suggest that the deficit may still be due to an underlying difficulty with language, rather than being rooted in attention or in executive function more generally.

Similar conflicting findings are reported in individuals with ASD. Some studies report deficits in both auditory and visual attention and inhibition, but with increased errors in visual tasks (Ciesielski, Knight, Prince, Harris, & Handmaker, 1995; Corbett & Constantine, 2006), whereas other studies report more pronounced deficits in the auditory domain compared with the visual domain (Hermelin & O'Connor, 1970; Rutter, 1983). Further studies report no clear deficits in either auditory or visual attention (Noterdaeme et al., 2001; Ozonoff & Strayer, 1997). It has also been hypothesized that children with ASD may struggle with executive function tasks because they are unlikely to encode rules verbally (Russell, Jarrold, & Hood, 1999). Interpreting results that suggest deficits in executive function in both children with SLI and children with ASD may be difficult because the children may have underlying language weaknesses that are affecting their performance on tasks of executive function.

The Use of Nonlinguistic Stimuli When Measuring Executive Function

To assess executive function in children with LIs, tasks that minimize language processes are likely to be beneficial when attempting to separate the influence of language from the desired measure of executive function. The most obvious strategy is through the use of nonlinguistic stimuli. However, increased stimulus processing demands for nonlinguistic stimuli may also compound the problem (Roebuck, Freigang, & Barry, 2016). A study in typically developing children observed that nonlinguistic tonal stimuli induced poorer performance in a simple attention task with two auditory tonal stimuli (high and low), compared with when the same task was completed with either two speech sounds (*ex* and *oh*) or their visual analogs (X and

O; Roebuck et al., 2016). Stimuli are characterized as linguistic or nonlinguistic in nature but rarely are finer distinctions made. In this case, the nonlinguistic tone condition induced poorer performance and reaction times (RTs) and was also correlated with working memory (as measured by auditory digit span). In this context, the auditory tonal stimuli (an apparently nonlinguistic task) induced greater demand than the stimuli that could be given a linguistic label. Additional processing demands in the nonlinguistic tone task may confound the interpretation of the desired measure. Instead of being a straightforward measure of attention, stimulus properties may differentially affect the demand on other processes (e.g., working memory). It is possible therefore that the use of nonlinguistic stimuli may be problematic when examining performance in children with language difficulties, given that SLI has also been associated with deficits in working memory (e.g., Ellis Weismer, Evans, & Hesketh, 1999; Windsor, Kohnert, Loxtercamp, & Kan, 2008). Deficits in working memory have also been reported in individuals with ASD (e.g., Joseph et al., 2005; Williams, Goldstein, & Carpenter, 2005). Potential challenges associated with using nonlinguistic stimuli may not be limited only to those children classified as having SLI but may also apply to other children who have language deficits.

Representation of Nonlinguistic Stimuli in Memory

Nonlinguistic stimuli are selected for use in cognitive tasks with the intention of reducing the demand on language processes. One factor that may be important to consider when selecting appropriate nonlinguistic stimuli is how they can be represented in memory. It may not simply be assumed that all nonlinguistic stimuli are represented in the same way or that they may add similar demands on other systems. The primary aim of the current study was to explore potential differences when using different types of nonlinguistic stimuli to assess performance in an inhibition task in relation to diagnostic category (i.e., typically developing [TD], SLI, and ASD) and between language status (i.e., normal language [NL] and LI).

When using nonlinguistic stimuli, participants may use nonlinguistic strategies to hold them in mind. That is, participants may be able to recall an echoic trace of a sound or form a visual or symbolic representation in memory. Alternatively, it is possible that linguistic strategies are used to assist performance. For example, individuals may assign an internal label or category to assist in differentiating a feature of the stimulus. In a go/no-go task, participants are required to respond with a button press to one stimulus and inhibit their response to another stimulus. When using linguistic stimuli, there is a clearly fixed identifier to assign to a stimulus (e.g., knowing to press a button when hearing a “three” but not a “nine”). When using a nonlinguistic stimulus, the absence of the linguistic element removes a clear identifier or concrete label to assist in establishing the representation. In a study where individuals were asked to categorize novel nonlinguistic “alien” sounds into those that should be approached or

avoided, participants learned categories faster if they were trained with labels (i.e., “leebish” and “gracious”) compared with those trained in the same way without labels (Lupyan & Casasanto, 2015; Lupyan, Rakison, & McClelland, 2007). Having a label, even for abstract sounds, assists in categorization. It is possible that the lack of a label for categorization in tasks using nonlinguistic stimuli may make the task more challenging. Returning to the example of nonlinguistic tonal stimuli, it has been suggested that English-speaking children may also have greater difficulty labeling pitch because the words “high” and “low” have multiple meanings (e.g., relating to pitch, space, and intensity [Costa-Giomi & Descombes, 1996]). French-speaking children performed better on the same task if they had been instructed using single-meaning terms “aigu” and “grave” compared with the multiple-meaning words “haut” and “bas.” Therefore, ambiguity, or lack of an associated label, may cause conflict when selecting an appropriate response.

The absence of a clear label or fixed category in nonlinguistic stimuli, however, does not negate participants’ use of a linguistic strategy. It is possible that individuals still assign linguistic features to nonlinguistic stimuli to assist in carrying out a given task. Evidence suggests that, even in a nonverbal *n*-back working memory task, activation was observed in the verbal subordinate system (Meegan, Purc-Stephenson, Honsberger, & Topan, 2004). If children use linguistic strategies to hold the stimulus in mind, it may be that nonlinguistic stimuli increase processing demands within the task, either in forming a linguistic identifier or in the ambiguity of not having one.

It is therefore possible that different nonlinguistic stimuli may induce different demands depending on the ease of representation. Nonlinguistic tonal stimuli are notably challenging to differentiate and categorize. High variation in frequency discrimination thresholds are reported between and within participants (Bishop, Carlyon, Deeks, & Bishop, 1999). One source of the variation may be influenced by the fact that tonal discrimination requires assigning a feature to a single attribute (Bishop et al., 1999). A representation in memory for a tone not only requires being able to hold a stimulus in mind but is also dependent on recalling what the other tone sounded like (i.e., to remember to press the button to the “low” sound, you have to recall what the “high” sound was like). The discrimination is relative. It is therefore possible that poorer performance for auditory nonlinguistic tonal stimuli is a reflection of the challenges associated with tonal discrimination and may not be observed with more complex stimuli that allow distinguishing the targets based on more than a single feature.

Current Study

The primary aim of the current study was to explore the potential effects of using different types of nonlinguistic stimuli when assessing children who had different diagnostic classifications and varying language abilities. Understanding whether selection of nonlinguistic stimuli might

influence task performance is important to make appropriate assumptions regarding the source of difficulty on a given task. In other words, can performance be assumed to be a consequence of a domain-general difficulty in executive function by using nonlinguistic stimuli?

An inhibition task was selected as an exemplar of executive function that both children with SLI and ASD have demonstrated variability in performance and that could also facilitate a simple stimulus comparison. Poorer performance has been observed when using nonlinguistic stimuli requiring a single tonal/pitch judgment (Roebuck et al., 2016). To establish whether the effects of stimulus variation in nonlinguistic stimuli extend to other stimuli, complex sounds that were nonlinguistic were selected that vary on more than one dimension (e.g., frequency, timbre, modulation, loudness). To avoid cross-modality differences, a single modality was selected. In this case, the auditory modality was examined because the primary deficit in developmental language disorder is with spoken language. To investigate whether familiarity of categorization assists performance, comparisons were made with nonlinguistic stimuli that have familiar high existing mental representations (i.e., duck quack and dog bark) and a second condition with no clear familiar representations (i.e., two different abstract complex sounds). It is predicted that forming a representation may be more challenging for abstract sounds compared with the familiar sounds that have highly familiar representations. Familiarity of categorization even in nonlinguistic stimuli may be related to language. However, language and memory are also highly related. The stimuli in the two conditions are manipulated by familiarity, and stimuli may be differentiated by how they are represented in memory. If representations are more difficult to form for the abstract stimuli, performance may also be related to ability to remember the stimuli, in either recalling or updating the representation relative to the other stimulus. The role of memory may be an important consideration given that weaknesses in memory are also associated with LI (e.g., Ellis Weismer et al., 1999; Windsor et al., 2008). A measure of nonlinguistic working memory was used to assess whether differences in working memory that are independent of language ability may explain difference in performance between conditions.

The overall aims of the study were to (a) investigate whether types of nonlinguistic auditory stimuli differentially affect inhibition, (b) determine whether performance differs between diagnostic category (TD, ASD, and SLI) or between children with and without an LI, and (c) assess what factors may be associated with poor performance specific to condition.

Method

Ethics Statement

This study was approved by the Education and Social Behavioral Institutional Review Board at the University of Wisconsin-Madison. Informed written consent was received

from parents, and all children participating gave verbal assent. All experimental procedures complied with the World Medical Association Helsinki Declaration as revised in October 2008.

Participants

Sixty children, aged 8–14 years, took part in the current study: 20 TD, 20 with ASD, and 20 with SLI. The sample of participants was re-recruited from a larger previous longitudinal study. Inclusion criteria required all participants to be native, monolingual speakers of American English; have a nonverbal IQ ≥ 85 (Wechsler Intelligence Scale for Children–Fourth Edition; Wechsler, 2003); and have normal hearing. Normal hearing was defined as passing a pure-tone screening at 20 dB at 1000, 2000, and 4000 Hz in at least one ear. Diagnostic groups were comparable in terms of chronological age ($p = .36$) and socioeconomic status ($p = .06$) as measured by maternal years of education (see Table 1). Diagnostic groups were not matched by gender. However, a high proportion of boys in the group with ASD (80%) reflects the inherent high male ratio in this population. On the basis of parent report, approximately 72% of the children in the study were White, 13% were multiracial, 10% were African American, and 5% were Asian. In terms of ethnicity, 12% were Hispanic/Latino and 88% were not Hispanic/Latino.

The children in the group with ASD had all received a clinical or educational diagnosis within their home communities (i.e., by a pediatrician, a developmental psychologist, a school psychologist, or an interdisciplinary team). Before participation in this study, the community diagnosis of each participant was confirmed by an experienced clinical psychologist using the Childhood Autism Rating Scale–Second Edition–High Functioning (CARS2-HF; Schopler, Van Bourgondien, Wellman, & Love, 2010). A minimum cutoff score of 25 was used, corresponding to the 10th percentile of CARS2-HF scores among individuals with ASD in the standardization sample. CARS2-HF scores were only collected for participants with ASD. However, all families completed a questionnaire that indicates concerns regarding ASDs as judged by a parental report screening measure, the Social Communication

Questionnaire (Rutter, Bailey, & Lord, 2003). The children in the group with SLI performed at least 1.25 *SDs* below the mean on one or more summary scores from the Clinical Evaluation of Language Fundamentals–Fourth Edition (CELF-4; Semel, Wiig, & Secord, 2003): Core Language, Receptive Language, or Expressive Language. Core Language scores (combination of Receptive and Expressive Language scales) were also at least 1 *SD* below the mean, indicating that there was some degree of delay in both language comprehension and production. The TD group had no history of language intervention and performed within 1 *SD* of the mean or higher on Core Language scores on the CELF-4.

To investigate the role of language ability, the same 60 children were also further categorized based on Core Language ability. LI was defined as more than 1.25 *SDs* below the mean for Core Language, indicating difficulties in expressive and/or receptive language abilities. On the basis of this criterion, there were 33 with NL ability, with CELF-4 Core Language standard scores > 81.25 , and 27 with LI, with CELF-4 Core Language standard scores < 81.25 . By assessing the groups based on language abilities, it is possible to assess whether performance is related to linguistic skill (as measured by expressive/receptive structural language ability) rather than anything integral to diagnostic category (TD, SLI, or ASD). These groups were comparable in terms of chronological age ($p = .31$), socioeconomic status ($p = .84$), and Social Communication Questionnaire ($p = .58$; Table 2).

Go/No-Go Tasks

The go/no-go task involved presentations of two different auditory stimuli. Participants were required to respond to a particular stimulus (with a single button press on a response box) that was regularly presented but to inhibit their response (not press the button) to the other stimulus. The experiment used a repeated measures design with two conditions using different types of complex auditory nonlinguistic stimuli, and all participants completed both conditions. Complex stimuli were selected so that the stimuli internally varied by multiple frequencies rather than being differentiated by a single tone. The two conditions

Table 1. Group characteristics by diagnostic category.

Diagnostic category	Age	SES ^a	Gender	NVIQ ^b	CELF-4	SCQ
	<i>M (SD)</i>	<i>M (SD)</i>	M:F	<i>M (SD)</i>	<i>M (SD)</i>	<i>M (SD)</i>
TD	11.5 (0.9)	17.7 (3.1)	8:12	114 (11)	111.0 (10.9)	4.0 (3.3)
ASD	11.2 (1.3)	15.3 (2.3)	16:4	107 (14)	86.5 (19.6)	19.2 (6.6)
SLI	11.7 (1.4)	15.8 (4.3)	14:7	100 (9)	79.9 (6.0)	9.3 (5.2)

Note. ASD = autism spectrum disorder; CELF-4 = Clinical Evaluation of Language Fundamentals–Fourth Edition (Semel et al., 2003); F = female; M = male; NVIQ = nonverbal IQ; SCQ = Social Communication Questionnaire (Rutter et al., 2003); SES = socioeconomic status; SLI = specific language impairment; TD = typically developing.

^aMeasured by maternal years of education. ^bMeasured by the Wechsler Intelligence Scale for Children–Fourth Edition Perceptual Reasoning Composite Score (Wechsler, 2003).

Table 2. Group characteristics by language ability.

Language ability	Age	SES ^a	Gender	NVIQ ^b	CELF-4	SCQ
	<i>M (SD)</i>	<i>M (SD)</i>	<i>M:F</i>	<i>M (SD)</i>	<i>M (SD)</i>	<i>M (SD)</i>
NL	11.2 (1.1)	16.6 (3.1)	20:13	113 (12)	105.9 (11.9)	10.3 (9.4)
(ASD_NL)	10.8 (1.4)	15.0 (2.3)	12:1	112 (13)	98.7 (9.8)	20.1 (6.9)
+ (TD)	11.5 (0.9)	17.7 (3.1)	8:12	114 (11)	111.0 (10.9)	4.0 (3.3)
LI	11.7 (1.3)	15.7 (3.8)	17:10	100 (9)	75.7 (9.9)	11.5 (6.4)
(ASD_LI)	11.2 (1.3)	15.7 (2.3)	4:3	98 (10)	70.0 (8.8)	17.6 (6.0)
+ (SLI)	11.7 (1.4)	15.8 (4.3)	14:7	100 (9)	79.9 (6.0)	9.3 (5.2)

Note. ASD = autism spectrum disorder; CELF-4 = Clinical Evaluation of Language Fundamentals–Fourth Edition (Semel et al., 2003); F = female; LI = language impairment; M = male; NL = normal language; NVIQ = nonverbal IQ; SCQ = Social Communication Questionnaire (Rutter et al., 2003); SES = socioeconomic status; SLI = specific language impairment; TD = typically developing.

^aMeasured by maternal years of education. ^bMeasured by the Wechsler Intelligence Scale for Children–Fourth Edition Perceptual Reasoning (Wechsler, 2003).

were familiar sounds (two sounds that could be easily recognized: a duck quack and a dog bark) and abstract sounds (two unfamiliar abstract sounds). All stimuli were normalized for amplitude and root mean square equalized for left–right balance using the software Audacity (Audacity Team, <http://audacity.sourceforge.net/>). The stimuli were presented at 65 dB SPL. The children were instructed to respond by pressing the button as quickly as they could whenever the “go” stimulus was presented and not to press the button when the “no-go” stimulus was presented. A fixation cross to orient attention to the middle of the screen was presented for 550 ms. Stimuli were presented for 200 ms, and participants could respond anytime within the onset of the stimulus and the interstimulus interval (1300 ms).

To familiarize the child with the task and the stimuli, a practice phase of eight trials with feedback was given (six go trials and two no-go trials). If the child made mistakes on the practice trials, the task was reexplained and the practice sequence was repeated before undertaking the experimental condition. Each condition consisted of 120 test trials. Go stimuli are presented for most of the trials (75%). A score is computed based on the number of commission errors (pressing the button on a no-go trial) and omission errors (failing to respond on go trials). Errors are reported in percentages. RT is only measured on correct responses. The order of conditions was counterbalanced across participants, and other tasks were included between conditions so that the child did not complete the two go/no-go tasks consecutively. Presentation of stimuli was fully randomized for each participant. All experimental tasks were presented using E-prime software (Version 2; Schneider, Eschman, & Zuccolotto, 2002), which automatically records accuracy and RT.

Working Memory Task

Participants completed a nonlinguistic *n*-back task that used abstract visual shapes as stimuli (Attneave & Arnoult, 1956; Vanderplas & Garvin, 1959). The *n*-back

task tests updating skills, requiring participants to decide whether each target matches a target presented *n* positions before. Participants pressed the green button on a response box for shape matches and the red button for shapes that did not match to the shape *n* positions before. Participants completed three conditions: 0-back, 1-back, and 2-back. Stimuli were presented for 1500 ms with an interstimulus interval of 500 ms. Each condition contained 40 trials including 10 target matches and 30 trials that did not contain target matches. A pseudorandomized sequence was used to ensure that there were at least two intervening trials between target shapes in the 0-back condition and target sequences were not repeated more than 10 times in both the 1- and 2-back conditions. For sample stimuli, see the Appendix. Accuracy scores are reported for the 1-back condition (per analyses conducted with TD children reported by Kaushanskaya, Park, Gangopadhyay, Davidson, & Ellis Weismer, 2017).

Statistical Analysis

Inhibition errors are reported in percentages. The percentages were not normally distributed (Shapiro-Wilk $p < .05$) and were transformed using a rationalized arcsine transformation (Studebaker, 1985). Back-transformed percentages are reported in the text. Comparisons were made using mixed repeated measures analysis of variance (ANOVA) and post hoc comparisons adjusted with Bonferroni correction. Multiple comparisons for Pearson correlations were Holm–Bonferroni corrected. All analyses were performed in SPSS (v.23).

Results

Role of Stimulus Type and Inhibition (Commission) Errors

To interpret the effect of stimulus type on inhibition errors, a repeated measures ANOVA comparing no-go

errors between stimulus type (familiar sounds and abstract sounds) and diagnostic groups (TD, SLI, and ASD) was conducted. There was no significant main effect of stimulus type, $F(1, 58) = 1.89, p = .18, \eta^2 = .03$, or diagnostic category, $F(1, 58) = 3.08, p = .05, \eta^2 = .01$, or an interaction between stimulus type and diagnostic category, $F(1, 58) = 1.75, p = .18, \eta^2 = .06$.

The same analysis was run for language ability (NL and LI). There was no significant main effect of stimulus type, $F(1, 58) = 2.64, p = .11, \eta^2 = .04$. There was a significant effect of language ability, $F(1, 58) = 6.47, p = .014, \eta^2 = .10$. The group with LI made more no-go errors ($\bar{X} = 14.5\%, SD = 14.0\%$) than the NL group ($\bar{X} = 7.3\%, SD = 6.6\%$). There was also an interaction effect between stimulus type and language ability, $F(1, 58) = 5.22, p = .026, \eta^2 = .08$. Post hoc with Bonferroni revealed that more inhibition errors were made in the abstract sound condition in children with LI ($\bar{X} = 16.7\%, SD = 14.3\%$) than in the familiar sound condition ($\bar{X} = 12.3\%, SD = 13.7\%, p = .011$). There was no difference in no-go errors in the NL group in the abstract sound condition ($\bar{X} = 6.9\%, SD = 5.9\%$) and the familiar sound condition ($\bar{X} = 7.8\%, SD = 7.3\%, p = .63$). The group with LI made more errors in the abstract sound condition ($\bar{X} = 16.7\%, SD = 14.3\%$) than the NL group ($\bar{X} = 6.9\%, SD = 5.9\%, p = .001$), but there was no significant difference in the familiar sound task between groups ($p = .226$; see Figure 1).

Role of Stimulus Type and RT

To interpret whether processing time was influenced by stimulus type, a repeated measures ANOVA compared correct RT across stimulus types (familiar sounds and abstract sounds) and diagnostic groups. There was no significant main effect of stimulus type, $F(1, 58) = 3.88, p = .054, \eta^2 = .06$, or diagnostic category, $F(1, 58) = 0.36,$

$p = .69, \eta^2 < .01$, or an interaction between stimulus type and diagnostic category, $F(1, 58) = 1.10, p = .34, \eta^2 < .04$.

The same analysis was run for language ability (NL and LI). There was also no significant main effect of stimulus type, $F(1, 58) = 3.79, p = .06, \eta^2 = .06$, or language ability, $F(1, 58) = 1.18, p = .28, \eta^2 = .02$, or an interaction between stimulus type and language ability, $F(1, 58) = 0.01, p = .95, \eta^2 < .01$, as illustrated in Figure 2.

Correlations With Performance Between Stimulus Types

In this experiment, the internal parameters were constant between conditions to reveal potential stimulus-specific effects. To further explore what factors may be involved in inhibition performance, a series of correlations were performed. To explore the association with language, correlations were completed with expressive and receptive language ability (CELF-4). To assess if there was an association with memory and performance, correlations were completed with a measure designed to test nonlinguistic working memory in terms of n -back accuracy (see summary of correlation findings in Table 3). A significant inverse correlation was observed for Receptive Language in the abstract sound condition, but not in the familiar sound condition. No other correlations were significant.

Discussion

The primary aim of the current study was to explore potential differences when using various types of nonlinguistic stimuli and to assess how they related to diagnostic category and language ability. No significant effects were observed for diagnostic category, but significant effects were observed by language status. The findings show that language ability can differentially affect performance even when using stimuli that are apparently nonlinguistic.

Figure 1. Percentage of inhibition errors across groups for each stimulus condition. Error bars indicate ± 1 SE. Asterisk (*) indicates significant effect, $p < .05$.

Figure 2. Accurate reaction time across groups for each stimulus condition. Error bars indicate ± 1 SE.

Table 3. Summary of *r* and *p* values (two-tailed) for Pearson correlations between stimulus conditions (*p* values corrected with Holm–Bonferroni correction).

Auditory nonlinguistic stimuli	Receptive language ^a	Expressive language ^a	<i>n</i> -back accuracy ^b
	<i>r</i> ; <i>p</i>	<i>r</i> ; <i>p</i>	<i>r</i> ; <i>p</i>
Familiar sounds	-.12; 1.000	-.07; 1.000	-.03; 1.000
Abstract sounds	-.38; .024*	-.36; .133	.06; 1.000

^aSubtest standard scores on the Clinical Evaluation of Language Fundamentals–Fourth Edition (Semel et al., 2003).
^bAccuracy for 1-back condition.
 **p* < .05.

The NL group performed comparably on both conditions, whereas the group with LI made more errors on the abstract sound condition but were equivalent to the NL group for familiar sounds. Performance on the abstract sound condition was also correlated with receptive language ability, but the familiar sound condition was not. Together, these findings suggest that the abstract sound task was more difficult for those with language issues. It appears that inhibition was not a general difficulty in the children with LI and was only apparent in the stimulus condition without clear preexisting representations. These findings have implications for selecting nonlinguistic stimuli in an attempt to remove a language confound and suggest that caution should be used when selecting stimuli for assessing executive function skills, as the type of “nonlinguistic auditory” stimuli may differentially impact performance. It is possible that underlying language weaknesses may make forming representations for unfamiliar abstract sounds more challenging, thus affecting performance because of a mechanism other than lack of inhibitory control.

Why Might Performance Be Poorer in the Abstract Sound Condition for Those With Language Weaknesses?

Nonlinguistic stimuli would not be expected to place demands on language processing; however, whereas the familiar sound condition was not related to language, the abstract stimuli were correlated with receptive language ability. The absence of a clear preexisting representation or an associated label may make the abstract stimuli more challenging to process. Although these stimuli are specifically selected with the intention of removing any linguistic demands, the results from this study suggest that not all auditory nonlinguistic stimuli may be independent from the language processes they are trying to circumvent. In previous categorization studies, individuals were able to learn categories better for nonlinguistic sounds if they were given labels to assist in their representation (Lupyan & Casasanto, 2015; Lupyan et al., 2007). In the current study, the familiar sounds were not given linguistic labels, although they mapped onto familiar existing concepts/categories. The abstract sounds do not come with a clear preexisting category, which proved more challenging for those with weaker language skills. Given the better performance by

participants in studies using nonlinguistic stimuli that are given a label, it is possible that the ambiguity of not having a linguistic identifier increases the difficulty level of the abstract stimuli that have no clear referent. It is important to note that increased inhibition errors do not appear to be a result of failure in distinguishing the stimuli absolutely: Indeed, accuracy was still high even in those with LI (83%). Moreover, the group with LI was able to respond to the stimuli as quickly for accurate responses as those with typical language abilities. These findings would appear to suggest that the increased errors in the abstract sound condition were not purely a reflection of a perceptual issue in speed of identifying the stimuli. The issue therefore is not whether they can identify the stimuli but how they do so.

It is also plausible that the association between language and errors in the abstract sound task is not due to language itself but rather a strategy that is common to receptive language ability (e.g., the way sounds may be categorized and represented). Further research would help elucidate whether differences are a consequence of a variable that is related to receptive language ability or whether the differences may be due to receptive language ability itself. Previous research findings suggest that processing effort influences capacity-limited systems such as the ability to sustain attention, with lapses in attention associated with exceeding processing resources (Kahneman, 1973). The same mechanism has been suggested for inhibition (Hitchcock, Dember, Warm, & Moroney, 1999). The ambiguity of not having a clear representation may impact processing effort in those with language weaknesses. When processing effort has been explored in relation to LI, children with SLI performed comparably with TD children in a low-load auditory condition but performed poorer with stimuli degraded by the addition of white noise (Spaulding et al., 2008). Previous studies (Adams & Gathercole, 2000; Ellis Weismer & Evans, 2002) have provided evidence to suggest that children with SLI may have more limited attentional capacities, but this only becomes apparent when processing demands exceed available resources. Although, in the current study, significant effects were observed by language status and not by diagnostic category, it is plausible that the difference between performance on the abstract and familiar sound tasks may be related to processing effort associated with language weakness. In this study, only the abstract condition was related to language ability: Performance on the

familiar sound condition was comparable with those with typical language skills. Poorer performance on executive function tasks in these populations therefore likely represents a consequence of dealing with higher processing demands associated with language difficulty, rather than an underlying deficit in inhibition/executive function per se. Indeed, although a meta-analysis indicated that children with LI were poorer on inhibition tasks than TD controls, the findings also suggested that it was not the severity of the language difficulty that was related to the frequency of inhibition errors (Pauls & Archibald, 2016).

The relationship between language and cognition is a complex one. Language and cognitive abilities are likely to interact bidirectionally, making the role of executive function and language ability inherently complex to tease apart. However, these findings appear to suggest that inhibition may not be directly related to the impairment in language but rather an underlying difficulty common to both language ability and processing the stimuli required for the abstract sound task. These findings support suggestions that weaknesses in language may lead to poor executive control. Language may act to facilitate the representation of information in working memory (Marcovitch & Zelazo, 2009). Other studies provide evidence in support of this assumption as suppression of language is associated with declines in executive function performance (Russell-Smith, Comerford, Maybery, & Whitehouse, 2014).

If children with language weakness struggle with representations for abstract stimuli, it may affect their ability to remember the stimuli. Forming a representation may be more challenging for abstract sounds compared with familiar sounds, which have highly salient representations. The role of memory may be an important consideration given that memory skills are associated with language processing (Baddeley, 2003; Ellis Weismer et al., 1999; Windsor et al., 2008). To assess if there was an association with memory ability and performance on the abstract sound task, correlations were completed with a measure designed to test nonlinguistic working memory (the *n*-back) task. However, there was no correlation between ability to process abstract sounds and working memory on this task. This finding may not exclude a relationship with auditory memory, as the memory task used abstract visual stimuli. It is plausible that memory effects may be modality specific. Given the differential findings between stimulus types in the inhibition task, the relevance of interpreting findings using nonlinguistic stimuli also applies to the executive function memory measures. Performance may be influenced by how the stimuli can be represented. However, these findings would argue against a domain-general relationship between working memory and difficulty on the abstract sound task.

What Stimuli Are Appropriate to Use?

“Nonlinguistic” stimuli are often chosen to reduce the demand on linguistic processing. In light of these findings, removing the role of language from cognitive tasks is challenging, even when using tasks and stimuli that are

in themselves “nonlinguistic.” If this cannot be achieved, what is the best approach to take? If the goal of the study was to assess a component of executive function, then the demand of identifying the stimulus should be minimal so as not to confound the interpretation with other processes. Controlling for perceptual characteristics such as duration and intensity does not imply control of demand. Consideration should be made for how easy it is to form a representation as well as what processes may be required in recalling the representation. Even within the category of nonlinguistic stimuli, there are many options that can be used for inhibition tasks such as directional arrows (Marton, Campanelli, Scheuer, Yoon, & Eichorn, 2012), shapes (Finneran et al., 2009), objects (Epstein, Shafer, Melara, & Schwartz, 2014), and hand actions (Henry, Messer, & Nash, 2012). An alternative approach would be to assess abilities using more than one stimulus type to represent the desired category of “nonlinguistic.” Testing a measure using different stimuli across a single category would allow a clearer assessment as to whether the child was struggling with a specific aspect of executive function or with a specific choice of a stimulus. This approach may be important not only to assess the specificity of a deficit to stimulus type (e.g., modality specific, domain general, or language specific) but, as in the current example, also to be able to conclude whether a deficit is specific to a component of executive function (e.g., inhibition). Further research to assess stimulus differences within the visual modality may also be useful, particularly before drawing conclusions about cross-modality discriminations. A further consideration when comparing task performance between groups would be to assess and consider variability within the control group. When comparing children with LI, fewer significant effects have been reported for nonlinguistic stimuli (Ebert & Kohnert, 2011). On the basis of the current findings, it is clear that factors other than simply removing the language element may be affecting the results. For example, greater variability in the control group because of factors independent of the desired measure may impact performance (Roebuck et al., 2016). Significant differences when using nonlinguistic stimuli may therefore be observed less because of high variability in performance rather than absence of a difference per se. Consideration should be made regarding stimulus choice both when interpreting findings as well as in selecting stimuli for future studies.

Conclusion

In the current study, children with language weaknesses did not show a general deficit in inhibition, but poor performance was specific to stimulus type, namely, abstract stimuli without familiar representations. Language weaknesses may make forming representations for unfamiliar abstract sounds more challenging than familiar sounds, suggesting a difficulty related to language rather than inhibition. The absence of a linguistic label in nonlinguistic stimuli does not prevent participants from possibly using language strategies in differentiating stimulus properties.

The findings also have implications for how to measure executive function in future studies. Caution is needed when selecting stimuli and for making comparisons across populations and studies.

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Appendix

Sample *n*-Back Stimuli